American Journal of Infection Control 40 (2012) 35-42

Contents lists available at ScienceDirect

American Journal of Infection Control

journal homepage: www.ajicjournal.org

Major article

Infection control through the ages

Philip W. Smith MD [a,*], Kristin Watkins MBA [b], Angela Hewlett MD [a]

[a] Division of Infectious Diseases, Department of Internal Medicine, University of Nebraska Medical Center, Omaha, NE
[b] Center for Preparedness Education, College of Public Health, University of Nebraska Medical Center, Omaha, NE

Key Words:
History
Hospitals
Nosocomial

To appreciate the current advances in the field of health care epidemiology, it is important to understand the history of hospital infection control. Available historical sources were reviewed for 4 different historical time periods: medieval, early modern, progressive, and post–World War II. Hospital settings for the time periods are described, with particular emphasis on the conditions related to hospital infections.

Approximately 1.7 million health care–associated infections (HAIs) occur in the United States each year.[1] Hospital infection control programs are nearly universal in developed nations and have significantly lowered the risk of acquiring a HAI since their inception in the mid 20th century. As we debate the preventability of HAIs, as well as the ethical and logistic aspects of patient safety, it is important to recall the historical context of hospital infection control. Public health infectious disease contexts are relevant to hospitalization, and we examine 4 time periods in the last half-millennium: medieval, early modern, progressive, and post–World War II. For each time frame, hospitalization-associated infectious diseases are discussed, and a hypothetical infection control agenda is presented. The selection of time periods is arbitrary but is designed to provide a representative overview of infections in hospitals through the centuries.

MEDIEVAL ERA (5TH TO 15TH CENTURIES)

Public health in the medieval era

Infectious diseases strongly impacted life in medieval times.[2] Bubonic plague killed about one-third of all people in Europe between 1347 and 1350; some towns were abandoned after losing two-thirds of their population in a single year. A 1471 outbreak killed 10% of the British population. Recurrent but less severe plague epidemics persisted up to 1650.

One of the few public health measures was the collection of bodies of plague victims. The bodies were left in the street to be picked up by carts and placed in mass graves outside of town.[3,4] Other infection control measures included hanging people who wandered in from an epidemic region into an uninfected area, shutting up plague victims in their homes, and burning clothing and bedding.[5]

In 1532, during the reign of Henry VIII, the plague was active throughout England and was especially severe in London. The king was advised to travel by waterway from London to escape the disease. On the order of the Privy Council, the Mayor of London wrote what is believed to be the first bill of mortality,[6] an important public health precedent. In the 16th century, public health laws started to appear throughout Europe.[7]

In addition to plague, epidemics of smallpox, influenza, dysentery, and typhus were frequent.[3] "English sweating sickness," an unknown Medieval febrile disease, was usually fatal.[8] Smallpox had a mortality rate of 20%-60%, and many survivors lost their sight. In some towns there were not enough survivors to bury the dead or harvest the crops.

Hospitals in the medieval era

The first European hospitals were established in the 12th century by religious orders. During the Middle Ages, hospitals were called "spittle houses" and provided care for the sick, insane, and destitute.[9] Persons of means preferred to receive care at home.[10] These hospitals were usually small and located outside the city walls, and had large burial grounds. In the 13th century, there were thousands of hospitals for the isolation of leprosy patients (leprosaria) in Europe. These were later converted to "pest houses" to

* Address correspondence to Philip W. Smith, MD, Division of Infectious Diseases, University of Nebraska Medical Center, 985400 Nebraska Medical Center, Omaha, NE 68198-5400.
E-mail address: pwsmith@unmc.edu (P.W. Smith).
Conflict of interest: None to report.

0196-6553/$36.00 - Copyright © 2012 by the Association for Professionals in Infection Control and Epidemiology, Inc. Published by Elsevier Inc. All rights reserved.
doi:10.1016/j.ajic.2011.02.019

provide care for plague patients.[11] Some hospitals were built over waterways that were used as sewers.[12]

In medieval times, hospitals were hazardous places (Fig 1). Epidemic infections killed large numbers of hospital patients during this period. Hospital infection and death rates were high. When a sick person entered a hospital, his or her property was disposed of, and in some regions a requiem mass was held, as if he or she had already died.[7] In addition to smallpox and plague, "hospital fever" (louse-borne typhus), typhoid, and dysentery killed large numbers of patients.

Surgery was generally performed by barber/surgeons with primitive surgical instruments using no asepsis or anesthesia. Postoperative mortality rates of 60%-80% were common, with most deaths due to so-called "hospital" (streptococcal) gangrene. Wound infection rates were also high because of unsanitary conditions and the use of cautery. As described in a medieval surgery text, cautery involved restraining the patient while a burning iron was pushed into the wound until it reached bone.[13] Alternatively, a boiling mixture of oil and treacle (a medicinal compound) was poured into wounds. Not surprisingly, patients experienced great pain and swelling around wound edges.[4]

Ground rabbit fur and mummy powder, the ground remains of mummies, were the most popular wound dressings, and attempts at asepsis were crude. Medicine consisted of herbs and various substances given by mouth, by enema, or topically. Typical ingredients requested by pharmacies included snake flesh, laurel berries, sheep dung, lye, cow kidney, antimony, alum, and earthworms.[13]

Hospital infection control in the medieval era

Although knowledge regarding the cause and spread of disease did not come about until the latter half of the 19th century, here we present a hypothetical Infection Control Committee (ICC) agenda to create a framework to help contemporary infection preventionists to understand historic problems. This hypothetical medieval ICC agenda might have included the following items:

- **Review of infections and mortality.** A listing of hospital infections would have included many feared diseases, including pneumonic plague, smallpox, tuberculosis (TB), diphtheria, and typhus. The ICC also might have noted a formidable hospital infection rate (90%), clean wound infection rate (80%), and hospitalization-associated death rate (40%-70%), which were typical of the times.
- **Surveillance denominator: beds or patients?** Any good hospital epidemiologist is concerned with denominator data, but this would be a difficult figure to grasp in the 15th and 16th centuries, because in many cases multiple patients occupied a single bed.[7,10,14] Accounts describe up to 6 persons in a bed, including a patient with febrile typhus occupying a bed with a mother in labor and a child next to a patient with TB who was constantly coughing.[11]
- **Staffing problems: plague.** Hospitals were difficult to staff, and in many cases inmates assisted patients. The plague decimated the population, including hospital staff. The position of infection control nurse (ICN) would have turned over frequently, not due to job dissatisfaction, but rather due to death from smallpox or plague.
- **Discussion of smallpox epidemic.** Nosocomial outbreaks were frequent in medieval European hospitals. Many of the outbreaks were related to smallpox, a common disease at the time.
- **Surgical site infections: cautery complications.** It was around this time that practitioners began to recognize that cautery did more harm than good.

Fig 1. Hôtel Dieu, Paris, circa 1500. The comparatively well patients (on the right) were separated from the very ill (on the left).

- **Problem of vermin in beds.** Hospitals were extremely unsanitary. Clean sheets were not the norm, and patients were expected to bring their own blankets and linens with them. In St. Mary's Bethlehem hospital in London, a herd of pigs was left free to root round the facility.[15] Mattresses were made of straw, and bed coverings were animal furs that were cleaned annually at best. These served as traps for all types of vermin, which occupied the beds with patients.
- **Hospital stench: windows.** The air in the sick wards was foul, so much so that attendants held vinegar-saturated sponges over their noses and mouths to combat the odors. Beds in medieval wards usually were placed under windows, which had the disadvantage of extreme cold in winter, but did provide some fresh air and relief from the fetid aromas.[7]
- **Policy for corpse removal.** The prompt removal of corpses, which we take for granted, would have been a radical idea at that time. Several accounts describe bodies that had been dead for 24 hours or longer and in a state of rigor mortis occupying a bed with multiple living patients.[7,9,14]

EARLY MODERN ERA (1500-1800)

Public health in the early modern era

Although the plague was no longer a major public health concern, infectious diseases remained the leading cause of death in Europe and the United States. In 1793, a yellow fever epidemic was responsible for the deaths of 10% of the population of Philadelphia, as well as 10 of its 80 physicians.[16] Smallpox killed 400,000 people per year in Europe, and measles killed at least as many people as smallpox. The early 1800s saw massive outbreaks of cholera, particularly in urban centers.[17] One-half to one-third of infected patients died.[18] Typhus caused epidemics with a 10% mortality rate; typhoid fever and dysentery were other common causes of outbreaks. Life expectancy at birth was 19-33 years.[19]

The only available treatments were purges, emetics, calomel (a tincture of mercury), opium, quinine, and bloodletting. A text describes an Italian woman who died at age 31 and had been bled 1,309 times during the last 4 years of her life.[19] In 1798, the average patient in Germany's Bamberg Hospital consumed 1 dram of opium, 195 g of camphor, 1 oz of liquor anodynes, 132 g of serpentara (snakeroot plant), 528 g of Peruvian bark, and 1 quart of distilled alcohol.[20]

Many important early medical and public health advances occurred during this period. In 1796, Edward Jenner deliberately

inoculated an 8-year-old boy with blisters from the hand of a milkmaid who had cowpox. This was the first "clinical trial" for smallpox vaccination—an effort to decrease the incidence and severity of a disease using a less- virulent form of the pathogen. The boy then successfully withstood a smallpox challenge, demonstrating immunity.[21]

After the yellow fever epidemic of 1793, Philadelphia created one of the first health departments in the country, and in 1801 completed the first municipal water system.[16] Quarantine was used for individuals suspected of having plague, typically for 42 days. It was common to have a "cleaning servant" sleep on woolen or cotton goods to rule out a contagious illness; when the person did not become ill, it was assumed that the goods were safe.[22] On arriving at a new city, travelers were often forced to wash from head to foot with vinegar, and mail from docking ships was exposed to burning sulfur to prevent the transfer of contagion.[23]

Hospitals in the early modern era

By 1800, 20,000 patients per year were hospitalized in London, and in 1801 the first hospital for infectious diseases was established.[11] In the United States, the first patient admitted to Massachusetts General Hospital in 1821 had diarrhea, extremity pain, and skin ulcers, possibly due to tertiary syphilis. He received cathartics, tree bark, and 5.3 g of corrosive sublimate of mercury. He later died, exhibiting symptoms of mercury poisoning.[24] Drugs were rarely tested for efficacy or safety.[15]

Wards were crowded, dirty, and poorly ventilated, and multiple patients still occupied a single bed.[9,25,26] At Bellevue Hospital in New York City, care was provided by prisoners or paupers, and there were frequent epidemics. At Blockley Hospital in Philadelphia, nursing duties were performed by inmates.[14] Persons of property or standing generally avoided hospitals and were cared for at home.[10]

A list of hospital-acquired infections during this period reveals many dreaded diseases. Sir Hector Cameron, an associate of Joseph Lister, reported that in the Glasgow Royal Infirmary in the mid-1800s, tetanus, erysipelas, septicemia, pyemia, and hospital gangrene were never absent from the hospital wards and were often epidemic.[27] Louse-borne typhus (called "hospital fever") was another important nosocomial infection; TB and cholera were often seen.

Hospital mortality was still significant, with rates of 25% common. Hospitals were dirty, ill-ventilated, and foul with infection. Patients were often admitted with a mild condition or an uncomplicated wound but acquired a virulent nosocomial infection while hospitalized.[14] According to a report of a military hospital, thousands of young men admitted to the hospital with slight injuries or venereal diseases died from serious infections acquired during their stay; a soldier entering a great battle was in less danger than one entering the hospital.[25]

Surgery was particularly deadly, due to the high rate of wound infections. Before 1800, women rarely survived caesarean section births,[11] and in large metropolitan hospitals, 40% of patients who underwent amputation died (Fig 2), most commonly from sepsis.[28] The usual cause was "surgical fever" or "surgical gangrene," most likely due to *Streptococcus pyogenes*. Surgeons themselves were unknowingly the cause of most infections. In central Europe, strolling barber/surgeons performed most surgeries, sandwiched into the working day between shaves and haircuts. Itinerant lithotomists removed bladder stones. Surgeons wore overcoats during surgery to protect their own clothes, and these were heavily crusted with dried blood and pus. Pieces of whipcord hung on the buttonholes of the coat, which were used to tie off arteries. Probes used to explore wounds were not cleaned between patients.[28]

Surgical techniques paid little attention to cleanliness. Instruments were often returned to their cases immediately after use, even if they had been dropped on the floor or used to amputate a purulent infected leg wound. Wounds were seldom washed, and few attempts were made to close incisions to protect wounds. Surgeons placed their gloveless hands directly into wounds.[29]

Fig 2. Amputation of arm, circa 1800.

Hospital infection control in the early modern era

A hypothetical early modern era ICC agenda might have included the following items:

- **Review of infections and mortality.** The ICC might have noted a very high hospital infection rate (60%), clean wound infection rate (50%), and hospitalization-associated death rate (10%-40%), which were typical of the times. An 8% mortality rate among doctors and attendants also would be seen.[14,30]
- **Discussion of dysentery epidemic.** Nosocomial epidemics were common and serious, and would have been a major topic of discussion. Smallpox and plague would have been less dominant in 1800 than in medieval times.
- **New isolation gown.** The physician's isolation garb was made of leather and included an elaborate mask with a bird-like beak. The beak often held antiseptics or pleasant-smelling substances to mitigate the foul odors of the hospital and sickroom.
- **Problem of lice in the hospital.** Lice and vermin were still a major problem, infesting hospitals, beds, and bedcovers.
- **Operating room sawdust: frequency of change.** The surgical wards of the late 18th century and early 19th century were described as having feces, urine, blood, and pus on the floors and sputum clinging to the walls. The stench was often unpleasant. Little cleaning was done in operating theaters, and sawdust usually covered the floors to absorb spilled blood and pus, similar to neighborhood butcher shops.[29]
- **Proposal to prohibit spitting on the wards.** One prominent physician of the time was accused of being excessively fussy when he prohibited spitting on the wards.[28]
- **Surgery theater nurse complaints.** A progressive ICN might have complained that handwashing was never done.

- **Policy on washing bandages between patients.** Sponges and water were used to bathe wounds on multiple patients, and bandages were reused without being washed.[29] A policy on washing bandages between patients would have been a major advance.

PROGRESSIVE ERA (1890S TO 1920S)

Public health in the progressive era

By the turn of the 20th century, life expectancy at birth was 45 years in the United States. The predominant infectious diseases were typhoid fever, malaria, yellow fever, typhus, smallpox, diphtheria, scarlet fever, measles, influenza, dysentery, cholera, and TB.[31] In 1900, deaths from influenza and pneumonia ranked first (with TB second) among all causes of mortality. Diphtheria, measles, scarlet fever, and whooping cough took the lives of one-fourth of all children between the age 1 and 14 years.[32] Mortality rates for diphtheria[33] and typhoid fever[34] were almost 50%. In 1901, 2 outbreaks of smallpox were reported from accidentally contaminated letters, and in 1901-1903, an outbreak of smallpox in Boston infected 1,600 people and caused 270 deaths.[35]

Quarantine signs on homes signaled the presence of diphtheria, scarlet fever, smallpox, or meningitis.[32] New Orleans addressed yellow fever by quarantining ships and blowing sulfurous oxide into ships' holds. The city's last yellow fever epidemic occurred in 1905, with 1,900 cases and 298 deaths. The New Orleans Board of Health recommended layering kerosene on drinking water barrels to kill mosquito eggs.[36]

Although this was a time of great advances in knowledge of infectious diseases, treatment for infections still consisted of enemas, topical rubs, and phlebotomy. Despite these practices, death rates from many common infections started falling in the 19th century.[37] The late 1800s brought exciting work in the area of bacteriology, particularly by Koch and Pasteur. In 1876, Koch published his work on anthrax, for the first time conclusively proving that a bacterium could be a specific infectious agent.[38] In 1886, Pasteur successfully immunized a boy who had been bitten by a rabid dog with spinal cord suspensions of inactivated rabies virus. Before this, rabies-prone wounds were treated by cauterization or by inserting long, heated needles deep into the wound or sprinkling gunpowder on the wound and lighting it.[39] In 1891, the first patient received diphtheria antitoxin. In 1893, the New York City Board of Health offered free diphtheria culture processing for specimens submitted by physicians;[40] over a 3-month period, 301 out of 431 specimens submitted were positive.

Remarkable advances in public health also occurred. The use of soap increased greatly in the late 1800s, and a bar of Ivory soap could be purchased for 7 cents in 1897.[41] Other advances included milk pasteurization, water treatment systems, sewer systems, and the development of state boards of health. By 1900, 40 of the 45 states had established health departments, and chlorination of public drinking water supplies had begun.[42]

Hospitals in the progressive era

The number of hospitals grew rapidly in the late 1800s;[43] by 1900, there were 4,000 hospitals in the United States. Hospitals had advanced significantly in the preceding 100 years. The hospital was no longer seen as a place of last resort,[10] largely due to advances in aseptic technique.[43] Electric lights had been introduced, although they often flickered or failed. The first X-ray units were being installed in hospitals. Intravenous fluid therapy and clinical thermometry had recently been introduced.[44,45]

Joseph Lister's breakthrough concept of surgical asepsis decreased postamputation mortality rates from 45% to 15% through preoperative handwashing and the use of disinfectant-soaked wound dressings. Lister also insisted that wound dressings be kept clean and wounds be kept covered to prevent airborne contagion.[4] William Halsted introduced rubber gloves for use in surgery in 1890. These concepts spread to US hospitals during this era.

Despite these advancements, hospitals still had minimal technology. One report describes a patient admitted to Philadelphia's Pennsylvania Hospital in 1900 with a broken leg. Although the hospital had recently purchased an X-ray unit, an X-ray was not taken. No blood was drawn, but urinalysis was performed. He went home 51 days later pronounced cured, and the total hospital record was 1 page long.[46]

Hospital infection control in the progressive era

This period saw great advances in hospital infection control. Ignaz Semmelweis was the first hospital epidemiologist, setting a precedent for step-by-step analysis of an outbreak and for tracing epidemics to a particular surgeon or practice (eg, going from the autopsy room to the operating room without washing hands). He saw 11 of 12 consecutive women die of puerperal (childbed) fever, and subsequently required that all providers who attended the patients first wash their hands in a watery solution of chlorinated lime. The mortality rate then dropped dramatically, from 18% to 2%.[47] He used a control group, and followed the change in rates of infection after instituting an infection control measure. Most physicians were highly critical of Semmelweis,[48] clinging to the prevailing theory that puerperal fever was caused by atmospheric conditions, despite the striking results of his infection control measures. Semmelweis became discouraged and withdrawn, and eventually died in an insane asylum.

Others besides Lister and Semmelweis contributed to the advances in hospital infection control.[49] American physician Oliver Wendell Holmes also noted a connection between birth attendants and puerperal fever. He was a pioneer in using epidemiologic methods to prove his theories, pushed for handwashing before the germ theory was known, and eloquently defended his views.[50] Florence Nightingale campaigned for hospital cleanliness and sanitation during the Crimean War and advanced hospital asepsis through her work and convictions.[49]

In 1900, the infection rate was lower than in 1800, but infections remained a significant problem in hospitals. TB, pneumonia, wound infections, and typhoid fever were common hospital infections, and dysentery, puerperal fever, wound gangrene, pyemia, influenza, and erysipelas were major killers.[10] The hospital mortality rate in many London hospitals approached 10%. In the late 1800s, the mortality rate after surgery was as high as 25%,[10] and the mortality rate for patients who underwent amputation was still >50% in many hospitals.[51]

A hypothetical progressive era ICC agenda might have been as follows:

- **Review of infections and mortality.** A nosocomial infection listing would have included such infectious diseases as TB, diphtheria, wound sepsis, measles, typhoid fever, puerperal sepsis, whooping cough, influenza, meningitis, and dysentery. The ICC also might have noted a hospital infection rate of 20% and a clean wound infection rate of 15%, although the latter could have been as low as 5% in some hospitals.[26]
- **Study of postamputation mortality.** The postamputation mortality rate was still high, as noted above.
- **Enforcement of Listerian technique (carbolic acid).** Some surgeons used a carbolic acid spray developed by Lister to

Fig 3. Clarkson Hospital operating room, Omaha, Nebraska, 1900. Reproduced with permission of the Nebraska Medical Center.

decrease airborne bacteria, and many hospitals noted a decrease in mortality when attention was paid to aseptic technique.

- **Proposal for tile floors.** Whereas the walls of older hospital wards were papered or painted, the walls and corridors of the newest hospitals were lined with glazed tiles, facilitating cleaning.
- **Puerperal sepsis outbreak.** Puerperal sepsis was still a common, and often lethal, surgical complication.
- **Operating room cleaning** (Fig 3). By 1900, surgical dressings were being prepared as packages that were placed on perforated trays in a wash boiler for sterilization, and nurses were thoroughly mopping every inch of the operating room between surgeries with a solution of bichloride of mercury.[52] Lighting was good, and hot and cold water were available.[53] Surgeons stopped operating in street clothes and began wearing gowns, masks, and rubber gloves.[4,11,31]
- **Policy on patient bathing.** By 1900, most hospitals gave patients a bath on admittance, often after lengthy debate, because many patients felt that water was weakening.
- **Isolation of TB and dysentery.** Isolation for diseases was a relatively novel idea and was not widely implemented.[52]

POST–WORLD WAR II ERA (1940s TO 1950s)

Public health in the post–World War II era

Public health efforts increased after World War II, and the incidence of TB, diphtheria, pertussis, measles, and puerperal sepsis had been declining even before the release of antibiotics. For example, <1% of deaths in England were due to infectious diseases in 1945, compared with approximately 25% in 1900;[54] in the United States, annual mortality fell from 797 deaths per 100,000 persons in 1900 to 75/100,000 in 1952.[55] Malaria in the United States was reduced to negligible levels by the 1940s.[42]

Antibiotic use was a new phenomenon, although 17 years had passed since Alexander Flemming noted the inhibitory effect of a contaminating mold (*Penicillium*) on *Staphylococcus aureus* colonies. Sulfanilamide and penicillin were new and potent drugs. The first dose of penicillin in the United States was given to a septic patient at Yale University Hospital in 1942.[56] Streptomycin had just been discovered and would greatly affect the treatment of TB. The deaths of 105 patients from ethylene glycol used as a diluent for sulfanilamide in 1937 led to a law requiring proof of safety before a new drug could be approved through the Federal Food, Drug and Cosmetic Act of 1938.[57]

The treatment of neurosyphilis was fever, induced by giving the patient malaria. Postwar science developed the field of genetic microbiology, and some believed that infectious diseases would soon be eliminated.

In 1946, the Centers for Disease Control and Prevention (CDC) was founded, evolving out of the Office of Malaria Control. The CDC's first weekly disease report included 161 cases of poliomyelitis, 4 cases of smallpox, 229 cases of diphtheria, and 25,041 cases of measles.[58]

Mobile X-ray units screened for TB cases. The TB mortality rate had fallen from 500 per 100,000 people in 1850 to 50/100,000 in 1945. Before anti-TB chemotherapy, treatment of TB consisted of

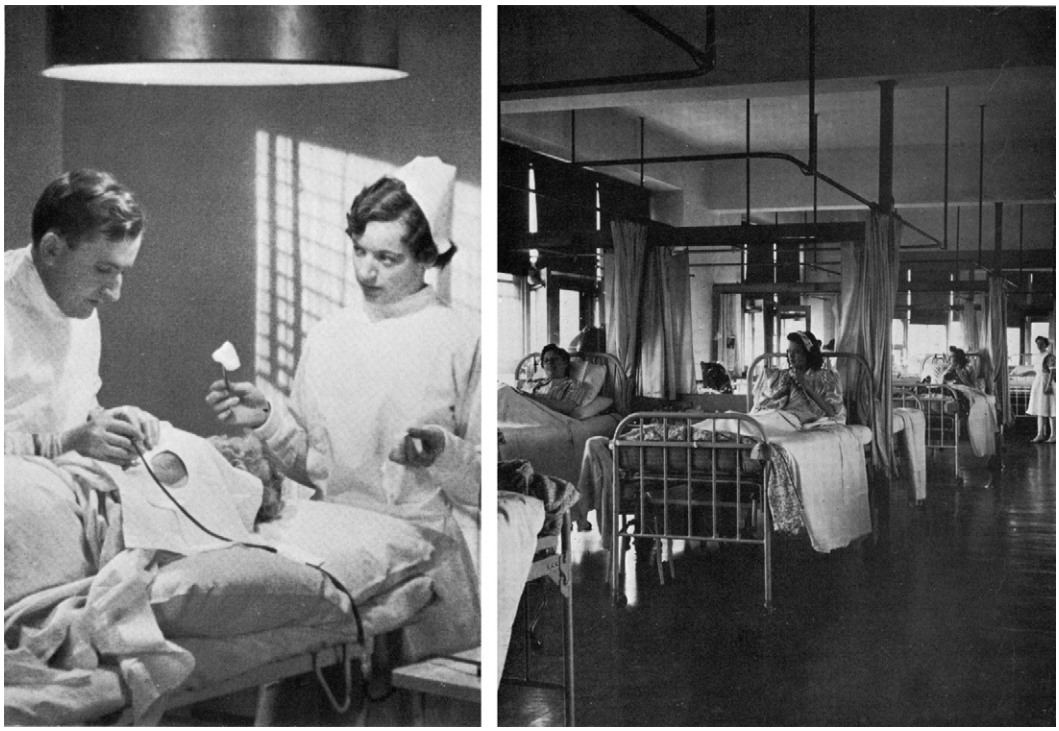

Fig 4. TB hospital circa 1945. Pneumothorax operation (left) and 1940s TB ward (right). Reproduced with permission of the Nebraska Chapter, American Lung Association Bullentin, March 1982.

rest, fresh air, hydrotherapy, cod liver oil, potassium iodide with menthol and oil of eucalyptus, and artificial pneumothorax. Ping pong balls were occasionally placed in the pleural space to prevent reexpansion of the lung (Lucite plumbage).[59] TB cases were treated in sanatoria; there were more than 700 of these facilities in the United States (Fig 4). The first anti-TB drugs would soon make the practice of artificial pneumothorax obsolete.

Hospitals in the post—World War II era

A hospital building boom in the United States began after World War II, fueled by the Hospital Survey and Construction Act of 1946 (Hill-Burton Act). The hospital had become a much safer place. The operating room was now thoroughly cleaned after each procedure, and standard surgical attire was finally routine. Catheters, gloves, syringes, and needles were boiled and reused, and gauze was ironed and reused.[60] The iron lung was a familiar device on the wards, providing ventilation for polio patients.

The incidence of streptococcal disease in hospitals began to decline in the late 1930s, due in part to the introduction of antibiotics. Following this decline, *Staphylococcus aureus* emerged as a predominant pathogen by the 1950s, in some measure related to antibiotic resistance. Major staphylococcal epidemics occurred throughout many hospitals, presenting as skin infections, boils, pneumonia, and sometimes fatal staphylococcal enterocolitis.[61] Medical and nursing staff members developed skin infections, and many were found to be nasal and dermal carriers of *S aureus*. The rapid spread of penicillin resistance was discouraging after the initial euphoria that greeted the drug's release.

Hospital employees were at significant risk for TB. Reports of 30%-100% of nurses with negative skin tests and nursing students who converted to positive during their training were published, 10%-23% of whom developed clinical TB.[62] High TB conversion rates in medical students were associated with attending autopsies of TB patients.

Hospital infection control in the post—World War II era

In an effort to address infection control issues like staphylococcal epidemics in an orderly fashion, the earliest formal infection control programs appeared in the 1950s.[63,64] However, as early as 1940 there was discussion of the application of epidemiology to hospital infections and the appointment of a single individual with the responsibility to collect data on hospital infections.[65] The first ICNs were appointed at this time. They often had a background in bacteriology, and quickly realized the critical importance of educating hospital personnel in hygiene practices.

Surveillance of hospital infections was instituted, and policies and procedures were developed. Early infection control programs focused on environmental cleanliness.[66-68] The presence of hazardous bacteria in dust led to an emphasis on proper technique when handling linens. Quarantine and isolation were emphasized because diseases such as smallpox and TB were seen in US hospitals, and Barnes Hospital in St. Louis opened an isolation ward in 1943.[69,70] There was early recognition of the value of cohort nursing and the fact that many patients with contagious diseases would be unknown, suggesting the need for a standard approach to all admissions.[71]

A hypothetical post—World War II ICC agenda might have covered the following topics:

- **Infection list.** The infection list (a precursor to the line listing) was developed by ICNs. A 1945 infection list might have recorded such diseases as pneumonia, sepsis, malaria, influenza, scarlet fever, dysentery, staphylococcal wound infection, measles, and poliomyelitis.[72]
- **Review of infections and mortality.** The ICC might have noted a hospital infection rate of ~10% and a clean wound infection rate of ~5%.
- **Staphylococcal epidemic discussion.** Staphylococcal epidemics were frequent and severe and would have been a topic of discussion.

- **Discussion of penicillin failures.** During this period, the ICC would be starting to hear reports of some failures in the treatment of staphylococcal infections with penicillin,[61] due to β-lactamase–producing *S aureus*. Antibiotic research was directed at a detailed chemical analysis of the penicillin molecule and a search for other useful byproducts of microbes.
- **Isolation policies and procedures.** The ICC likely would have discussed handling of linens and dishware from isolation rooms.
- **Surgical mask problem.** Surgical technique and equipment was advancing, but even at this early stage, compliance with hygienic practices was an issue. Antibiotics permitted surgery in patients previously considered to be at high risk.
- **Transfer of TB cases to sanatoria.** Persons with TB were immediately placed in sanatoria for therapy.[59] Chest X-rays were used to screen all hospital admissions for TB.
- **Isolation of veterans with malaria.** Malaria could cause nosocomial cases through mosquito vectors, so screen doors could be seen on the wards occupied by World War II Pacific theater veterans.
- **Education on infection control.** ICNs were first recognizing the value of education in preventing infections in the hospital, both of the person responsible for infection control of other hospital personnel by the ICN.[65,73,74]

CONCLUSION

Hospital infection control has grown exponentially since its beginning in the mid-20th century.[75,76] In 1976, the Joint Commission on Accreditation of Healthcare Organizations instituted the requirement that a hospital have an infection control program in place in order to receive accreditation. Multiple professional organizations, including the Association for Practitioners in Infection Control and the Society for Hospital Epidemiology of America, emerged with the intent of improving hospital infection control practices to prevent HAIs.[76] In the mid-1980s, the CDC initiated the National Nosocomial Infections Surveillance System to provide a mechanism for reporting HAIs, which evolved into the current National Health Safety Network in 2005. The Study on the Efficacy of Nosocomial Infection Control in the 1970s affirmed that comprehensive hospital infection control programs could indeed prevent HAIs.[77]

Currently, we have sophisticated data collection/analysis techniques, molecular epidemiology, multiple vaccinations, potent antibiotics, prevention bundles, performance improvement methodologies, advances in sterilization and disinfection, environmental control measures, and widely available hand hygiene agents. The progress in hospital infection control over the last several centuries is remarkable, although infections continue to pose a substantial risk to hospitalized patients.

Historical information on the exact infectious risks of hospitalization is fragmentary, and HAI risks were not uniform for all hospitals. Nevertheless, we can form a composite impression that hospitalized patients were at great risk of acquiring infections, and that this risk has been progressively declining over the last 500 years, long before formal infection control programs existed. Medieval times remind us of the great risk of hospital infections with minimal infection control efforts; subsequent eras demonstrate the improvement in HAI prevention as basic infection control and medical technology advanced. Current infection control lives in its historical context. As F. Scott Fitzgerald reminds us: “So we beat on, boats against the current, borne back ceaselessly into the past.”[78]

Acknowledgment

We thank Dr Judith Stern and Elaine Litton for their excellent editorial and secretarial assistance.

References

1. Klevens RM, Edwards JR, Richards CL, Horan TC, Gaynes RP, Pollock DA, et al. Estimating health care–associated infections and deaths in US hospitals, 2002. Public Health Rep 2007;122:160-6.
2. McNeill WH. Plagues and peoples. Garden City [NY]: Anchor Press; 1976.
3. Gottfried RS. Plague, public health and medicine in late medieval England. In: Bulst N, Delort R, editors. Maladies et société. XII ed. Paris: Editions du CNRS; 1989. p. 337-65.
4. Bettmann O. A pictorial history of medicine: a brief, nontechnical survey of the healing arts from Aesculapius to Ehrlich, retelling with the aid of select illustrations the lives and deeds of great physicians. Springfield [IL]: Thomas; 1956.
5. Sherman ID. The power of plagues. Washington DC: ASM Press; 2006. p. 70.
6. Creighton C. A history of epidemics in Britain from AD 664 to the extinction of plague. Cambridge [UK]: Cambridge University Press; 1891.
7. Gottfried RS. The black death: natural and human disaster in medieval Europe. New York: Free Press; 1983.
8. Thwaites G, Taviner M, Gant V. The English sweating sickness, 1485 to 1551. N Engl J Med 1997;336:580-2.
9. Massengill SE. A sketch of medicine and pharmacy and a view of its progress by the Massengill family from the fifteenth to the twentieth century. Bristol [TN]: SE Massengill; 1943.
10. Rosenberg C. The care of strangers: the rise of America’s hospital system. New York: Basic Books; 1987.
11. Porter R. The Cambridge illustrated history of medicine. Cambridge [UK]: Cambridge University Press; 2001.
12. Walters EM. Infection control up to the renaissance. Nursing Times 1981; 77(Suppl):16-8.
13. Borgognnoni T. The surgery of Theodoric: ca AD 1267. Campbell E, Colton J, translators. New York: Appleton Century Crofts; 1955.
14. Goodnow M. Outlines of nursing history. Philadelphia: Saunders; 1916.
15. Rawcliffe C. The hospitals of later medieval London. Med Hist 1984;28:1-21.
16. Foster KR, Jenkins MF, Toogood AC. The Philadelphia yellow fever epidemic of 1793. Sci Am 1998;279:88-93.
17. Shapin S. Sick city: maps and mortality in the time of cholera. New York [NY]: The New Yorker; 2006. p. 110-5.
18. Morris RJ. Cholera, 1832: the social response to an epidemic. New York: Holmes & Meier; 1976.
19. Estes JW. The practice of medicine in 18th-century Massachusetts: a bicentennial perspective. N Engl J Med 1981;305:1040-7.
20. Ackerknecht EH. Therapeutics from the primitives to the 20th century. New York: Hafner Press; 1973.
21. Barquet N, Domingo P. Smallpox: the triumph over the most terrible of the ministers of death. Ann Intern Med 1997;127:635-42.
22. Velimirovic B, Velimirovic H. Plague in Vienna. Rev Infect Dis 1989;11:808-26.
23. Ambrose CT. Osler and the infected letter. Emerg Infect Dis 2005;11:689-93.
24. Scully RE, Galdabini JJ, McNeely BU. Case records of the Massachusetts General Hospital. Weekly clinicopathological exercises: case 51-1976. N Engl J Med 1976;295:1421-9.
25. Duncan LC. Medical men in the American revolution, 1775–1783. Carlisle [PA]: Medical Field Service School; 1931.
26. LaForce FM. The control of infections in hospitals, 1750–1950. In: Wenzel RP, editor. Prevention and control of nosocomial infections. Baltimore: Williams and Wilkins; 1997.
27. Libby W. The history of medicine in its salient features. New York: Houghton Mifflin; 1922.
28. Haagensen CD, Lloyd WEB. A hundred years of medicine. New York: Sheridan House; 1943.
29. Alexander JW. The contributions of infection control to a century of surgical progress. Ann Surg 1985;201:423-8.
30. Jones C, Sonenscher M. The social functions of the hospital in eighteenth century France: the case of the Hôtel Dieu of Nunes. French Hist Stud 1983;13: 172-214.
31. Cruickshank R. Hospital infection: a historical review. Br Med Bull 1944;2: 272-6.
32. Kampmeier RH. From watchful waiting to antibiotics. JAMA 1989;262:2433-6.
33. Kass AM. Infectious diseases at the Boston City Hospital: the first 60 years. Clin Infect Dis 1993;17:276-82.
34. Anonymous. Has progress been made in the medicinal treatment of typhoid fever? JAMA 1890;23:809-13.
35. Albert MR, Ostheimer KG, Breman JG. The last smallpox epidemic in Boston and the vaccination controversy, 1901–1903. N Engl J Med 2001;344:375-9.
36. Carrigan JA. The saffron scourge: a history of yellow fever in Louisiana, 1796–1905. Lafayette [LA]: Center for Louisiana Studies, University of Southwestern Louisiana; 1994.
37. Kass EH. History of the specialty of infectious diseases in the United States. Ann Intern Med 1987;106:745-56.

38. Kaufmann SH. Robert Koch, the Nobel Prize, and the ongoing threat of tuberculosis. N Engl J Med 2005;353:2423-6.
39. Krasner RI. Pasteur: high priest of microbiology. ASM News 1995;61:575-9.
40. Kleinman LC. Lessons from the history of diphtheria. N Engl J Med 1992;326:773-7.
41. Aiello AE, Larson EL, Sedlak R. Hidden heroes of the health revolution: sanitation and personal hygiene. Am J Infect Control 2008;36:S128-51.
42. Centers for Disease Control and Prevention. Achievements in public health, 1900–1999: control of infectious diseases. MMWR Morb Mortal Wkly Rep 1999;48:621-9.
43. Vogel MJ. The invention of the modern hospital, Boston 1870–1930. Chicago: University of Chicago Press; 1980. p. 2.
44. Cosnett JE. The origins of intravenous fluid therapy. Lancet 1989;1:768-71.
45. Dominguez EA, Bar-Sela A, Musher DM. Adoption of thermometry into clinical practice in the United States. Rev Infect Dis 1987;9:1193-201.
46. Howell JD. Technology in the hospital: transforming patient care in the early twentieth century. Baltimore: Johns Hopkins University Press; 1995.
47. Wyklicky H, Skopec M. Ignaz Philipp Semmelweis, the prophet of bacteriology. Infect Control 1983;4:367-70.
48. Miller PJ. Semmelweis. Infect Control 1982;3:405-9.
49. Larson E. A retrospective on infection control, part 1: nineteenth century—consumed by fire. Am J Infect Control 1997;25:236-41.
50. Gathright EC. A letter from Oliver Wendell Holmes, 1809–1894: in memory of the centennial of his death. Infect Control Hosp Epidemiol 1995;16:607-11.
51. Cohen J. Hospital gangrene: the scourge of surgeons in the past. Infect Control Hosp Epidemiol 1999;20:638-40.
52. Writers' Program, Kansas. Lamps on the prairie: a history of nursing in Kansas. Emporia [KS]: Emporia Gazette Press; 1942.
53. Drinkwater H. Fifty years of medical progress, 1873–1922. New York: Macmillan Co; 1924.
54. Thomson D. The ebb and flow of infection. JAMA 1976;235:269-72.
55. Armstrong GL, Conn LA, Pinner RW. Trends in infectious disease mortality in the United States during the 20th century. JAMA 1999;281:61-6.
56. Grossman CM. The first use of penicillin in the United States. Ann Intern Med 2008;149:135-6.
57. Wax PM. Elixirs, diluents, and the passage of the 1938 Federal Food, Drug and Cosmetic Act. Ann Intern Med 1995;122:456-61.
58. Centers for Disease Control and Prevention. MMWR Morb Mortal Wkly Rep 1996;45:532-6.
59. Fisher L, editor: American Lung Association special anniversary issue: 100 years of tuberculosis. American Lung Assoc Bulletin; March 1982. New York [NY]: American Lung Association; 1982. p. 9.
60. Goulding FA, Torrop HM. The practical nurse and her patient. Philadelphia: Lippincott; 1955.
61. Selwyn S. Changing patterns in hospital infection. Nurs Times 1972;68:643-6.
62. Sepkowitz KA. Tuberculosis and the health care worker: a historical perspective. Ann Intern Med 1994;120:71-9.
63. Centers for Disease Control and Prevention. Public health focus: surveillance, prevention and control of nosocomial infections. MMWR Morb Mortal Wkly Rep 1992;41:783-7.
64. Nahmias AJ, Eickhoff TC. Staphylococcal infections in hospitals: recent developments in epidemiologic and laboratory investigations. N Engl J Med 1957;265:74-81.
65. Barnes ME. Applied epidemiology in a general hospital. JAMA 1940;115:1757-60.
66. Van den Ende M, Spooner E. Reduction of dust-borne bacteria in a ward by treating floor and bedclothes. Lancet 1941;i:751-2.
67. Crosbie WE, Wright HD. Diphtheria bacilli in floor dust. Lancet 1941;i:656-7.
68. Heeren RH. Handling contaminated linen. Mod Hosp 1941;57:52-3.
69. Mitman M. Quarantine in general hospitals. Lancet 1943;241:400-1.
70. Bradley FR. A six-year report on care of communicable diseases. Hospitals 1950;24:62-4.
71. Burgdorf AL. Hospitalization of cases of communicable diseases together with certain considerations of the isolation techniques and nursing procedures used. Am J Public Health 1949;39:1289-94.
72. Miles AA. Observations on the control of hospital infections. Br Med Bull 1944;2:276-81.
73. Perkins JE. Isolating communicable disease. Mod Hosp 1940;55:85-6.
74. Felsen J, Wolarsky W. The hospital epidemiologist. Hospitals 1940;14:41-3.
75. Sydnor ERM, Perl TM. Hospital epidemiology and infection control in acute-care settings. Clin Micro Rev 2011;24:141-73.
76. Larson E. A retrospective on infection control, part 2: twentieth century—the flame burns. Am J Infect Control 1997;25:340-9.
77. Haley RW, Culver DH, White JW, Morgan WM, Emori TG, Munn VP, et al. The efficacy of infection surveillance and control programs in preventing nosocomial infections in US hospitals. Am J Epidemiol 1985;121:182-205.
78. Fitzgerald FS. The great Gatsby. New York: Charles Scribner's Sons; 1925.